L Number	Hits	Search Text	DB	Time stamp
1	23	model with (variable and water and velocit$3)	USPAT; US-PGPUB	2002/09/19 15:36
2	5	model with (variable and water and velocit$3) and seismic	USPAT; US-PGPUB	2002/09/19 15:42
3	26	"5261406" "540371" "5502687" "6263284" "5570321"	USPAT; US-PGPUB	2002/09/19 15:43
4	4	("5261406" "540371" "5502687" "6263284" "5570321") and velocity and (vertical and time and correction) and moveout	USPAT; US-PGPUB	2002/09/19 15:51
5	2263	process$4 with (water time velocities) and seismic and data	USPAT; US-PGPUB	2002/09/19 15:54
6	0	process$4 with (water adj time adj velocities) and seismic and data	USPAT; US-PGPUB	2002/09/19 15:55
7	0	process$4 with (water adj3 time adj3 velocities) and seismic and data	USPAT; US-PGPUB	2002/09/19 15:55
8	0	process$4 and (water adj3 time adj3 velocities) and seismic and data	USPAT; US-PGPUB	2002/09/19 15:56
9	96	process$4 and (water adj3 velocities) and seismic and data	USPAT; US-PGPUB	2002/09/19 15:56
10	10	process$4 and (water adj3 velocities) and seismic and data and cmp	USPAT; US-PGPUB	2002/09/19 15:56

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TITLE: Selection of seismic modes through amplitude characteristics

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Abstract Text - ABTX (1):

The instant invention is generally directed toward methods of using an AVO-type analysis on unstacked seismic data to identify subsurface exploration prospects. More particularly, a new method of identiflying and displaying converted mode seismic reflections is provided that has significant advantages over that in the prior art. Additionally, the instant invention can be used to attenuate or eliminate seismic reflections such as multiples that are not flattened by conventional velocity analysis. Further, a method is disclosed that provides for identification and display of only those seismic reflections deemed consistent with the usual or expected AVO behavior. Finally, another aspect of the instant invention involves the use of statistical goodness of fit measures, such as the Coefficient of Determination, to create a seismic display that is indicative of the degree to which each time slice in a gather conforms to a proposed AVO model.

Brief Summary Text - BSTX (4):

A seismic survey represents an attempt to image or map the subsurface of the earth by sending sound energy down into the ground and recording the "echoes" that return from the rock layers below. The source of the down-going sound energy might come, for example, from explosions or seismic vibrators on land, or air guns in marine environments. During a seismic survey, the energy source is placed at various locations near the surface of the earth above a geologic structure of interest. Each time the source is activated, it generates a seismic signal that travels downward through the earth, is reflected, and, upon its return, is recorded at a great many locations on the surface. Multiple source/recording combinations are then combined to create a near continuous profile of the subsurface that can extend for many miles. In a two-dimensional (2D) seismic survey, the recording locations are generally laid out along a single line, whereas in a three dimensional (3D) survey the recording locations are distributed across the surface in a grid pattern. In simplest terms, a 2D seismic line can be thought of as giving a cross sectional picture (vertical slice) of the earth layers as they exist directly beneath the recording locations. A 3D survey produces a data "cube" or volume that is, at least conceptually, a 3D picture of the subsurface that lies beneath the survey area. In reality, though, both 2D and 3D surveys interrogate some volume of earth lying beneath the area covered by the survey.

Brief Summary Text - BSTX (6):

A modern seismic trace is a digital recording (analog recordings were used in the past) of the acoustic energy reflecting from inhomogeneities or discontinuities in the subsurface, a partial reflection occurring

each time there is a change in the elastic properties of the subsurface materials.

Brief Summary Text - BSTX (7):

The digital samples are usually acquired at 0.002 second (2 millisecond or "ms") intervals, although 4 millisecond and 1 millisecond sampling intervals are also common. Each discrete sample in a conventional digital seismic trace is associated with a travel time, and in the case of reflected energy, a two-way travel time from the source to the reflector and back to the surface again, assuming, of course, that the source and receiver are both located on the surface. Many variations of the conventional source-receiver arrangement are used in practice, e.g. VSP (vertical seismic profiles) surveys. Further, the surface location of every trace in a seismic survey is carefully tracked and is generally made a part of the trace itself (as part of the trace header information). This allows the seismic information contained within the traces to be later correlated with specific surface and subsurface locations, thereby providing a means for posting and contouring seismic data--and attributes extracted therefrom--on a map (i.e., "mapping").

Brief Summary Text - BSTX (8):

The data in a 3D survey are amenable to viewing in a number of different ways. First, horizontal "constant time slices" may be taken extracted from a stacked or unstacked seismic volume by collecting all of the digital samples that occur at the same travel time. This operation results in a horizontal 2D plane of seismic data. By animating a series of 2D planes it is possible for the interpreter to pan through the volume, giving the impression that successive layers are being stripped away so that the information that lies underneath may be observed. Similarly, a vertical plane of seismic data may be taken at an arbitrary azimuth through the volume by collecting and displaying the seismic traces that lie along a particular line. This operation, in effect, extracts an individual 2D seismic line from within the 3D data volume.

Brief Summary Text - BSTX (9):

Seismic data that have been properly acquired and processed can provide a wealth of information to the explorationist, one of the individuals within an oil company whose job it is to locate potential drilling sites. For example, a seismic profile gives the explorationist a broad view of the subsurface structure of the rock layers and often reveals important features associated with the entrapment and storage of hydrocarbons such as faults, folds, anticlines, unconformities, and sub-surface salt domes and reefs, among many others. During the computer processing of seismic data, estimates of subsurface rock velocities are routinely generated and near surface inhomogeneities are detected and displayed. In some cases, seismic data can be used to directly estimate rock porosity, water saturation, and hydrocarbon content. Less obviously, seismic waveform attributes such as phase, peak amplitude, peak-to-trough ratio, and a host of others, can often be empirically correlated with known hydrocarbon occurrences and that correlation applied to seismic data collected over new exploration targets.

Brief Summary Text - BSTX (11):

These effects can sometimes be identified visually by arranging the moved-out seismic traces from a single gather (or from a composite "super" gather that includes more than one conventional gather) in order of the offset of each trace from the shot and then visually comparing the amplitudes on the near traces with the amplitudes on the far traces at the same time point. (See, for example, page 25 of "AVO Analysis: Tutorial & Review", by J. Castagna, appearing in Offset-Dependent Reflectivity--Theory and Practice of AVO Analysis, John Castagna and Milo Backus (editors), SEG Press, pp. 3-36, 1993, the

disclosure of which is incorporated herein by reference). Alternatively, various AVO attributes may be calculated from the unstacked gather, each gather conventionally yielding one AVO attribute trace. By combining many of these attribute traces, entire sections or volumes may be formed that superficially resemble conventional seismic data, but which are, in reality, displays that can be used to quickly identify AVO-type effects.

Brief Summary Text - BSTX (12):

The traditional AVO-type analysis involves fitting a parametric curve (i.e., a function characterized by one or more constant coefficients) to seismic amplitudes taken from a constant time "slice" of a moved-out CMP or other (e.g., common reflection point, "CRP", or common conversion point, "CPC") gather. However, the typical parametric representation is only appropriate for use with compressional or "P" type reflections. When other seismic propagation modes are present, the fitted curve may fail to adequately model the seismic data, which might potentially lead to spurious or masked hydrocarbon indicators.

Brief Summary Text - BSTX (13):

By way of explanation, seismic energy propagates through the earth in one of two modes: compressional or "P" waves and shear or "S" waves, either of which might be generated by a wide variety of seismic sources. "Converted waves" are those waves that travel first as one type of wave and then the other, the conversion between wave-types happening at any seismic discontinuity. If the conversion happens once only, from an incident P-wave to a reflected S-wave, this mode will be referred to herein as a "C-wave". Additionally, multi-path (or multiple) reflections are a well known coherent noise source in seismic processing and exploration. A multiple reflection, as is well known to those skilled in the art, arises when seismic energy arrives at the surface after being reflected from more than one interface. For example, it is quite common in offshore settings to find that the original seismic signal "bounces" between the surface of the ocean and the ocean bottom a number of times during the seismic recording. This results in a repeating waveform that appears at regular time intervals throughout every recorded seismic trace (a "multiple"), the precise time separation being determined by the depth of the water, the velocity of sound in water at the recording location, and the shot-receiver offset. Additionally, it is also common to find interbed multiples in on-shore--and off-shore--surveys, these sorts of multiples arising when the seismic signal bounces up and down between two rock units. "Primary" reflections are P-mode waves that are reflected only once within the subsurface.

Brief Summary Text - BSTX (15):

Heretofore, as is well known in the seismic processing and seismic interpretation arts, there has been a need for a method of automatically identifying and extracting or suppressing particular seismic wave modes from the traces in a seismic survey. Additionally, this method should provide an improved method of conducting AVO analyses on seismic data. Accordingly, it should now be recognized, as was recognized by the present inventor, that there exists, and has existed for some time, a very real need for a method of seismic data processing that would address and solve the above-described problems.

Brief Summary Text - BSTX (19):

According to a first aspect of the instant invention, there is provided a method of attenuating non-primary reflection events (e.g., converted and multi-path arrivals) in an unstacked gather. In more particular, if seismic data are processed so that only the P-wave reflections are time-aligned in a moved-out CMP gather, and the aligned data are then fitted by an AVO polynomial, evaluation or "expansion"

of that polynomial using the resultant estimated coefficients will tend to reproduce only the aligned reflectors. This approach will thus discriminate against and, in many cases effectively remove, coherent noise in the form of non-aligned modes (such as multiples) from the gather. Polynomial expansion will be discussed at some length below. The resulting unstacked traces are then usable by seismic processes such as prestack migration or stack.

Brief Summary Text - BSTX (21):

According to a third aspect of the instant invention, there is provided a novel means of identifying and eliminating from an unstacked gather reflectors corresponding to converted wave mode reflections. In more particular, by fitting an AVO-type polynomial to the seismic data at each time level and observing the relative magnitudes and signs of the coefficients so calculated, it is possible to differentiate flattened P-wave reflections from flattened C-wave reflections. Then, if polynomial expansion is applied only to those combinations of coefficients that do not match the converted-wave signature, a gather may be reconstructed in which these modes are attenuated or eliminated. Alternatively, if the calculated AVO polynomials are expanded only for those time points that match the required signature, a converted-wave-only section may be obtained.

Brief Summary Text - BSTX (22):

According still another aspect of the instant invention, there is provided a method of polynomial expansion of AVO equations that is conditioned on the degree to which the calculated AVO polynomial fits the unstacked seismic data at each time point. In the preferred embodiment, the AVO polynomial is fit to the data and a statistical goodness of fit measure (such as the Coefficient of Determination, r.sup.2) is also calculated, .sup.2r being one of a number of statistical quantities that measure the degree to which the seismic amplitude values are represented or "fit" by the AVO polynomial. Then, the AVO polynomials are expanded for those time levels that have an associated r.sup.2 that is high, i.e., relatively "near" 1.0, thereby producing a gather with non-zero samples only where the data are well modeled by the AVO equation. This will produce a gather that contains seismic energy only at those times that are well predicted by the AVO model. Among the many circumstances that could give rise to a poor functional fit are departures of the seismic data from the AVO model, which might be caused by noise contamination from the generation of coherent energy such as multiples, head waves, or processing artifacts, or contamination by excessive random (incoherent) noise. Seismic data that have been made free of these effects are ideally suited for further processing, as at least some of the contaminated noise will have been attenuated or removed. Alternativley, the AVO polynomials may be expanded only for those time levels which correspond to a small (i.e., near 0.0) value of r.sup.2, thereby making visually apparent those portions of the data that are not well fit by the chosen AVO model.

Detailed Description Text - DETX (5):

The methods disclosed herein would best be implemented in the form of a computer program 30 that has been loaded onto a general purpose programmable computer 50 where it is accessible by a seismic interpreter or processor. A general purpose computer 50 includes, in addition to mainframes and workstations, computers that provide for parallel and massively parallel computations, wherein the computational load is distributed between two or more processors. As is also illustrated in FIG. 5, some sort of velocity model 40 is preferably specified by the user and provided as input to the processing computer program. The exact means by which such models are created, digitized, stored, and later read during program execution is unimportant to the instant invention and those skilled in the art will recognize that this might be done any number of ways.

Detailed Description Text - DETX (10):

After the seismic data are acquired, they are typically taken to a processing center where some initial or preparatory processing steps are applied to them. As is illustrated in FIG. 4, a common early step is the specification of the geometry of the survey (step 90). As part of this step, each seismic trace is associated with both the physical receiver (or array) on the surface of the earth that recorded that particular trace and the "shot" (or generated seismic signal) that was recorded. The positional information pertaining to both the shot surface position and receiver surface position are then made a permanent part of the seismic trace "header," a general purpose storage area that accompanies each seismic trace. This shot-receiver location information is later used to determine the position of the "stacked" seismic traces. It would normally be after the velocity analysis/NMO processing steps that one aspect of the instant invention would first be applied. An NMO correction adjusts the samples in each seismic trace according to their distance from that shot so that energy returning from the same reflectors are aligned at the same time on the seismic trace. This process is well known to those skilled in the art and will not be discussed further herein, although additional details are available in Yilmaz, cited previously, at pages 154-166, the disclosure of which is incorporated herein by reference.

Detailed Description Text - DETX (12):

As is suggested in FIG. 4, any digital sample within a stacked seismic volume is uniquely identified by an (X, Y, TIME) triplet: the X and Y coordinates representing some position on the surface of the earth, and the time coordinate measuring a recorded arrival time within the seismic trace (step 110). For purposes of specificity, it will be assumed that the X direction corresponds to the "in-line" direction, and the Y measurement corresponds to the "cross-line" direction, as the terms "in-line" and "cross-line" are generally understood to mean in the art. Although time is the preferred and most common vertical axis unit, those skilled in the art understand that other units are certainly possible might include, for example, depth or frequency. Additionally, it is well known to those skilled in the art that it is possible to convert seismic traces from one axis unit (e.g., time) to another (e.g., depth) using standard mathematical conversion techniques. That being said, the discussion that follows will be framed largely in terms of "time" as a vertical axis measure, but that choice was made for purposes of specificity, rather than out of any intention to so limit the methods disclosed herein. Further, when "time" is described hereinafter as a vertical axis of a seismic trace, that term should be broadly construed to also include any other applicable vertical axis, including depth or frequency.

Detailed Description Text - DETX (16):

The CMP method is well understood by those skilled in the art of seismic exploration and is a widely employed means of achieving high signal-to-noise ratios in seismic data. FIG. 1 broadly illustrates one key aspect of the CMP method--as well as some possible variants--for a typical seismic experiment. In general, each recorded trace will contain reflections of various modes from many reflecting horizons at many arrival times. A "gather" of traces from many such source-receiver combinations is formed through repetitions of this experiment and appropriate procedures to form accumulations of those traces that have a common source-receiver midpoint. In the case of 3D data, data all lying within the same "bin" (as that term is known and used in the art) constitute a gather. Through summation or stacking of these gathers or redundant seismic signals, reflection events which correspond to assumed ray paths are enhanced while other events are reduced. Before summation, the CMP gathers are processed using certain conventional procedures which include the normal moveout technique to compensate for the different ray paths, offset distances, and travel times.

Detailed Description Text - DETX (18):

In seismic exploration, it is often desirable to display the gathers without summation (i.e., unstacked) in order to analyze the lateral variations in reflectivity. It is well known to those skilled in the art that the lateral variation in the amplitude of the primary P-wave reflection may be approximately described (c.f., Aki and Richards, 1980; Thomsen, 1994, and especially, Castagna, 1993 page 20-21) at every time by:

Detailed Description Text - DETX (19):

where .phi. is the angle of incidence--with respect of the vertical, see FIG. 2--of a seismic wave on a rock interface, and A, B, and C are arbitrary constants, the values of which are typically estimated from the seismic data. In practice, .phi. might be estimated in any number of ways, but a preferred way is by ray-tracing through a geologic model of the subsurface.

Detailed Description Text - DETX (24):

Standard statistical curve fitting techniques, such as least squares regression, can be used to derive the parameters A, B, and C from the seismic data at each time point. That is, if the array X[n,m], m=1, M, n=1, N, represents a time-aligned CMP gather, where M is the number of traces and N the number of samples in each trace, then at each time point "n" it is conventional to solve the following matrix equation (which corresponds to equation (1) for the unknown constant coefficients A, B, and C): ##EQU1##

Detailed Description Text - DETX (25):

where subscripts have been temporarily added to the constants A, B, and C (i.e., A.sub.n, B.sub.n, and C.sub.n) to make clear their dependency on the time-level at which the regression is calculated; and where the symbol ".apprxeq." has been used to indicate approximate equality in the sense that the constants A.sub.n, B.sub.n, and C.sub.n are to be chosen so as to make the left and right sides of the equation as nearly equal as possible. Additionally, the angle-of-incidence parameter has been augmented with two subscripts, i.e., .phi..sub.l,n, to reflect its dependency on the trace offset and the time level at which the parameter is calculated. Finally, note that rather than using the unknown earth reflectivity at each time point, R.sub.p (.phi.), the seismic amplitude, X[m,n], is used instead. This substitution is commonly made by those skilled in the art and its propriety need not be discussed here (e.g., see Demirga, Coruh, and Costain, "Inversion of P-wave AVO," appearing in Offset-Dependent Reflectivity--Theory and Practice of AVO Analysis, John Castagna and Milo Backus (editors), SEG Press, pp. 287-302, 1993, the disclosure of which is incorporated herein by reference).

Detailed Description Text - DETX (29):

The values of the coefficients so calculated are seismic attributes that are then displayed as an aid to the explorationist. For example, a seismic section or volume might be composed entirely of calculated A values from equation (3), one A value being calculated at each time level of every gather. Since A is usually regarded as being representative of the zero offset reflectivity, a section or volume of these coefficients yields a spatial display that at least theoretically approximates the image that would have been obtained if a zero-offset survey had been conducted. Similarly, a section that consists of the quantity "B" at every time point, is a so-called "gradient stack," which can be very useful in emphasizing portions of the section, wherein AVO effects may be found. Additionally, many mathematical combinations (e.g., sums, differences, ratios, products, etc.) of the calculated coefficients have may also be displayed.

Detailed Description Text - DETX (30):

Another useful quantity that is frequently calculated in connection with regression-based AVO attributes is the degree to which the data are adequately "fit" by the selected equation at each time point. The statistical Coefficient of Determination, "r" or "r.sup.2 " as that quantity is known to those skilled in the art, is one conventional measure of the "goodness of fit" of the model by the data. A large value of r.sup.2 (i.e., a value near 1.0) indicates that the data are well fit at that time level by the selected equation. However, a value of r.sup.2 near zero signifies that the seismic amplitudes analyzed at that particular time are not well fit by the selected model and, hence, are possibly contaminated by various coherent noise sources, such as multiples, head waves, converted waves, or processing artifacts, or by various incoherent (random) noise sources, such as wind or cultural sources in land recordings.

Detailed Description Text - DETX (31):

Additionally, it is well known that evaluation of the previous expression using the estimated parameter values yields a best-fit prediction of the reflectivity for that trace and time. That is, if A', B', and C' are coefficient values obtained by minimization of the equation (5), then the value

Detailed Description Text - DETX (32):

provides a "best" estimate of the reflectivity on the single trace "m" at time "n" according to this model. This process is called "expansion" of the polynomial, per Wright, in U.S. Letters Patent 4,677,597, "Method For Enhancing Common Depth Point Seismic Data", the disclosure of which is incorporated herein by reference.

Detailed Description Text - DETX (35):

Turning now to a first aspect of the instant invention, there is provided a method of pre-stack attenuation of reflection events containing residual moveout through the use of a polynomial expansion of AVO regression-type attributes. FIGS. 6A, 6B, and 6C illustrate the general steps of the instant method.

Detailed Description Text - DETX (36):

As a preferred first step, the reflectors 602 in a seismic gather 600 are flattened in a manner well known to those skilled in the art (FIG. 6A). This would preferably be done by way of a semblance-type velocity analysis 610 and NMO steps 618 discussed previously, although manual or automatic picking and flatting of prominent reflectors would also be acceptable. In either case, the goal is to acquire a seismic gather 615 in which the P reflectors have been at least approximately flattened in time--a gather that has been corrected for travel time between shot and receiver. The NMO process (at least theoretically) places reflected seismic energy from a given reflector at the same two-way travel time on every trace, no matter what the offset of the trace from shot. Finally, although the instant method preferably operates on flattened gathers, those skilled in the art will recognize that physical flatting of the traces in the gather is not an absolute requirement. However, the implementation of the instant method is much simpler if the gathers have been pre-flattened. So, in the text that follows "flattening" will be used to describe traces in a gather that have actually been flattened as well as those traces for which a collection of same travel-time samples can be extracted.

Detailed Description Text - DETX (37):

Given a flattened gather 615, as a next step AVO-type regression coefficients are computed, preferably at each time interval in the trace, although the precise time-range over which the AVO

attributes is calculated is immaterial to the instant invention. In practice, the explorationist might specify a zone of interest that was bounded by a starting and ending sample number or time.

Detailed Description Text - DETX (38):

In that case, the program that implements the instant invention might only calculate the selected AVO coefficients over that restricted time interval, rather than throughout the entire trace.

Detailed Description Text - DETX (39):

In the preferred embodiment the coefficients of equation (1) are estimated for each time slice according to the matrix expression (5). As part of that process, a first time slice at the nth sample number is extracted 619 from the flattened gather 615. Then, for each of the extracted samples, an angle of incidence (i.e., "AOI") is preferably calculated. This might be done many different ways, but a preferred method is by ray tracing through a structural model of the subsurface of the earth. As is well known to those skilled in the art, the subsurface model need not be particularly accurate and might contain, by way of example, velocities from a conventional stacking velocity analysis. Methods for creating subsurface models such as would be appropriate for use with the instant embodiment are well known to those skilled in the art. Alternatively, and as was discussed previously, rather than calculating an angle-of-incidence, a formulation which does not require computation of the AOI but instead uses a related measure--such as the use of trace offset in equation (4) supra--might be used. Those skilled in the art realize that many other variations and arrangements are also possible.

Detailed Description Text - DETX (40):

Given the AOI values for each sample 625 a curve is next fit 630 through the (AOI, amplitude) pairs to yield estimates of the AVO attributes A, B, and C. Although the plot 630 suggests that there is a linear relationship between AOI and amplitude, in reality the function that best fits these data points will be typically be more complicated and may require the solution of a non-linear system of equations. In the preferred embodiment, though, the functional form introduced in equation (1) will be solved, thereby producing estimates of the parameters A, B, and C at this time level.

Detailed Description Text - DETX (41):

Note that the form of the equation solved in the previous step is not a critical part of the instant invention. That is, other functional forms (such as, for example, those presented in equations (2) through (4)) could be used instead without substantial modification of the previous steps. The main requirement is that a function characterized by constant coefficients be fit to the amplitude data from at least one time level, thereby producing estimates of those constant coefficients for use as AVO parameters as detailed below.

Detailed Description Text - DETX (43):

The previous steps would typically be repeated for many time-slices, perhaps for every time slice in the gather. The seismic values that result from the expansion step are now suitable for further seismic processing as individual seismic traces or as a gather and might be, for example, migrated and/or then stacked. In more particular, the traces in this gather should exhibit attenuation of undesired reflections with respect to the primary or other desired P-wave reflections. The reason for this is as follows. Since the typical AVO model is designed to accommodate P-data only, the curve fit will tend to accurately model the actual data only when the reflection is a P-wave. In the event that the reflection is, for

example, a C-wave or multiple, the equation will not fit the observed amplitudes very well and the reconstructed (expanded) data will not resemble the original amplitudes to any great extent.

Detailed Description Text - DETX (44):

On the other hand, when the modeled reflector is a P event, the curve fit will generally be much better, so that the expanded fit will accurately the model the data present at that time: in effect, the original seismic values will be reproduced. Thus, this expansion provides a method of pre-stack attenuation of non-P-wave reflectors. This effect is generally illustrated in FIG. 6. Low velocity event 605 is seen cutting across P-reflections 602. This low velocity event might be a multiple, a converted wave, etc. After the application of moveout 618, estimation of the coefficients 635, and expansion of the polynomial 640, attenuation of the low velocity event 655 should be observed.

Detailed Description Text - DETX (46):

to produce as many estimates of the coefficients. So, the phrase "expansion of the polynomial" will be used herein in the sense of including using the estimated coefficient values, along with some measure of the angle of incidence (or offset from the shot), in a particular functional form to obtain an estimate of a seismic value for a particular offset and time.

Detailed Description Text - DETX (49):

According to a second aspect of the instant invention, there is provided a method of selection and extraction from an unstacked gather seismic information of potential significance to the exploration for oil and gas. As is generally illustrated in FIG. 3, as a first step a gather is extracted 305 from the seismic survey. The gather might be obtained from a 2-D or 3-D survey. Next, the gather is flattened (step 310), preferably by application of the NMO correction using stacking velocities. The calculation of the AVO coefficients then proceeds (much as has been described previously) by identifying same-time samples (step 315); determining of the angle of incidence for each sample so identified (step 320); and solving the selected AVO modeling equation for its characterizing constants (step 325). In FIG. 3, the solution is expressed as the solution of a linear matrix equation. However, in some cases it might be necessary to solve a nonlinear system of equations, depending on the exact functional form of the modeling equation. In either case, the goal is to obtain estimates of the coefficients for this particular time level.

Detailed Description Text - DETX (50):

However, rather than unconditionally expanding the polynomial as was described previously, in the instant embodiment the polynomial is expanded only if its coefficients meet some predetermined criterion. Thus, the resulting gather will consist of reconstructed data values at some time levels, and some alternative "null" values (usually "zero") at other time levels.

Detailed Description Text - DETX (52):

That is, unless the coefficients A.sub.n and B.sub.n, satisfy the indicated inequality, a value of zero is stored in that output location. Note that this will result in all of the samples in a given time slice being replaced either by expanded values or the value zero.

Detailed Description Text - DETX (53):

The previous inequality is based on the observation that when the coefficients A and B have the same

arithmetic sign, that condition is often associated with gas--or some other "unusual" lithologic condition--in the subsurface. Thus, when the product AB is greater than zero, that fact is signaled to the explorationist by expanding the polynomial for that time slice. If the data are subsequently stacked and displayed, the non-zero portions of the stacked section can be rapidly located within a large seismic volume and, if they merit it, subjected to further study aimed at verifying the cause of the anomaly.

Detailed Description Text - DETX (57):

According to a third aspect of the instant invention, there is provided a means for identifying C-wave reflections in a seismic gather by fitting an AVO-type polynomial to the seismic data and observing the relative sizes of the coefficients so calculated. Once the C-mode reflectors have been identified, the AVO polynomial can be expanded for those time slices that are not C-mode, thereby attenuating or eliminating C-waves from the section. Alternatively, the AVO polynomial can be expanded only for those time slices that appear to be C-mode, thereby producing a converted-wave-only section. Further, more than one polynomial might be calculated at each time interval and the polynomial that best fits the data in that time interval expanded. In any case, the resulting seismic section or volume can be used by the explorationist to identify and eliminate converted wave reflections from his or her interpretation.

Detailed Description Text - DETX (63):

Note that in the instant embodiment the C-mode reflections are assumed to have been flattened by the velocity analysis/NMO step. In the first embodiment discussed previously, the reflectors that are attenuated will be those that are not flattened. Here, the goal is the recognition and separation of converted mode reflections that may have been mistaken for pure P-mode reflections, and which have been flattened--either intentionally or accidently--by the NMO process. This is particularly important in the case of converted waves which, unlike "C-waves", reconvert back to P-waves after a short shear leg. For example, a wave might convert from a P mode to an S mode at the top of a salt body; reflect from the base of the salt as an S wave; and then convert back to P in transmission through the top of the salt. This process might be modeled according to the following expression:

Detailed Description Text - DETX (69):

According still another aspect of the instant invention, there is provided a method of polynomial expansion of AVO equations, wherein the rule for polynomial expansion is dependent on the degree to which the unstacked seismic data fits the calculated AVO polynomial at each time slice. The instant method is substantially similar to the previous method, except that the rule for expanding the polynomial differs.

Detailed Description Text - DETX (70):

In the preferred embodiment, the seismic data will be pre-processed, sorted into gathers, and flattened as described previously. Also as before, a zone of interest will be selected by the seismic processor. Then each gather is selected and processed one slice at a time to estimate the unknown coefficients of the AVO modeling equation. Then, the polynomial is expanded as before, but a different rule is used to determine whether or not to display the expanded results. That is, ##EQU10##

Detailed Description Text - DETX (71):

where r.sub.n.sup.2 is the statistical Coefficient of Determination for the previous fit for the nth time slice and d is an arbitrary positive value selected in accordance with the discussion that follows.

Detailed Description Text - DETX (73):

where X[n,.cndot.] is the arthmetic average over m of the X[n,m]; where Mean SS is the sum of squares about the mean (the first term in the numerator) and SSE is the sum of squares due to lack of fit by the regression (the second term in the numerator). Those skilled in the art will recognize that there are many other ways to formulate the Coefficient of Determination. However, the essential feature of this statistical measure is that it returns some indication of the goodness of fit of the AVO model to the data at that time slice.

Detailed Description Text - DETX (74):

In terms of the instant embodiment, relatively larges values of the Coefficient of Determination indicate that the seismic data at those time levels are well modeled by the AVO equation and, thus, correspond at least approximately to expected P-mode AVO effects. Thus, in this instant embodiment, the AVO polynomials are expanded only for those time levels that have an associated r.sup.2 that is high, i.e., "near" 1.0. The inventors have found that a value of d near 0.50 is a good choice in many situations. In the alternative, of course, the polynomial might be expanded only for those time slices with values or r.sub.n.sup.2 near zero, however the interpretation of the resulting display would then be different.

Detailed Description Text - DETX (75):

For those polynomials not expanded, a constant substitute value is chosen as a replacement seismic value for each trace at that time level. In the preferred embodiment, and as is illustrated in the previous equation, the value zero has been chosen as the substitute value. However, that value was selected for purposes of convenience only and many other choices might be used instead. A main purpose of replacing the non-expanded time levels with a constant value is to make those time levels readily recognizable by the explorationist who will be viewing and analyzing the output from this method. In the text that follows, the substitute value will be typically be taken to be equal to zero, but it should be remembered that this was done for purposes of specificity only.

Detailed Description Text - DETX (76):

A display formed in this manner provides a means for the explorationist to rapidly identify within a section or volume those locations in time and space where the data are accurately fit by the particular AVO model used. Using this display, in conjunction with some of the other displays discussed previously, would allow the explorationist to not only identify AVO anomalies, but also to judge whether or not the AVO affect occurred by chance or in concert with the selected AVO model.

Detailed Description Text - DETX (77):

The preceding discussion suggests still another way to recognize converted mode reflections in an unstacked gather. Note that equation (5) is exact for converted-mode reflections, whereas equations (1) to (4) are applicable only to P reflections. Thus, if both equations are applied to the same time-slice of seismic data values, the AVO equation that is most appropriate should "fit" the data better. This suggests the following rule for recognizing and displaying C-mode reflections: ##EQU12##

Detailed Description Text - DETX (78):

where r.sup.2 now is calculated with respect to the fit function of equation (5). Another variant of the

instant idea could be used to construct a section or volume that maps the location of P and C-mode reflectors at all times. Let r.sup.2 (1) be the Coefficient of Determiination calculated for a fit of equation (1) and r.sup.2 (5) be the same quantity calculated for equation (5). That is, at each time slice both equation (1) and equation (5) will be fit to the same seismic values. A corresponding Coefficient of Determination will also be calculated for each. Then, the following display rule could be used to create indicator variables that would point to those portions of the seismic section that tend to appear more like P or C-modes: ##EQU13##

Detailed Description Text - DETX (82):

Additionally, the term "angle of incidence" or AOI should be interpreted herein in the broadest possible sense of that term. The preferred meaning of AOI is the one that is conventional in AVO analysis: angle of incidence at a particular time level. However, in the broader sense, it should be taken to include any offset-dependent quantity, whether or not dependent on time.

Detailed Description Text - DETX (84):

Finally, in the previous discussion, the language has been expressed in terms of operations performed on conventional seismic data. But, it is understood by those skilled in the art that the invention herein described could be applied advantageously in other subject matter areas, and used to locate other subsurface minerals besides hydrocarbons, e.g., coal. By way of additional examples, the same approach described herein could be used to process and/or analyze multi-component seismic data, shear wave data, magneto-telluric data, cross well survey data, full waveform sonic logs, or model-based digital simulations of any of the foregoing. Additionally, the methods claimed herein after can be applied to transformed versions of these same data traces including, for example: frequency domain Fourier transformed data; transformations by discrete orthonormal transforms; instantaneous phase, instantaneous frequency, analytic traces, and quadrature traces; etc. In short, the process disclosed herein can potentially be applied to any collection of geophysical time series, and mathematical transformations of same, but it is preferably applied to a collection of spatially related time series containing structural and stratigraphic features. Thus, in the text that follows those skilled in the art will understand that "seismic trace" is used herein in a generic sense to apply to geophysical time series in general.

Claims Text - CLTX (10):

(g) performing steps (c) through (f) a predetermined number of times, thereby producing a plurality of predicted samples; and,

Claims Text - CLTX (15):

(j) performing steps (b) to (i) a predetermined number of times, thereby producing a predetermined number of stacked seismic attribute traces.

Claims Text - CLTX (24):

(e4) performing steps (e1) to (e3) a predetermined number of times, thereby producing a predetermined number of chosen functions and a predetermined number of goodness of fit values associated therewith,

Claims Text - CLTX (62):

said seismic survey being comprised of unstacked seismic traces, and, each of said unstacked seismic traces being associated with a gather and consisting of digital samples, each of said digital samples being associated with a time level;

Claims Text - CLTX (65):

(d) selecting at least one digital sample from each flattened seismic trace, each of said at least one digital samples being associated with a same time level;

Claims Text - CLTX (69):

(h) performing steps (d) through (g) a predetermined number of times, thereby producing a plurality of predicted samples; and,

Claims Text - CLTX (83):

(h) performing steps (e) through (g) a plurality of times, thereby producing a plurality of chosen functions, a plurality of associated indicator values, and a predetermined number of associated coefficient estimates;

Claims Text - CLTX (86):

(k) performing steps (c) through (j) a predetermined number of times, thereby producing a predetermined number of chosen indicator values; and,

Claims Text - CLTX (88):

20. A method according to claim 19, wherein steps (b) through (l) are performed a predetermined number of times, thereby producing a predetermined number of seismic attribute traces.